Productivity growth, ‘catching-up’ and trade in livestock products

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Table of Contents

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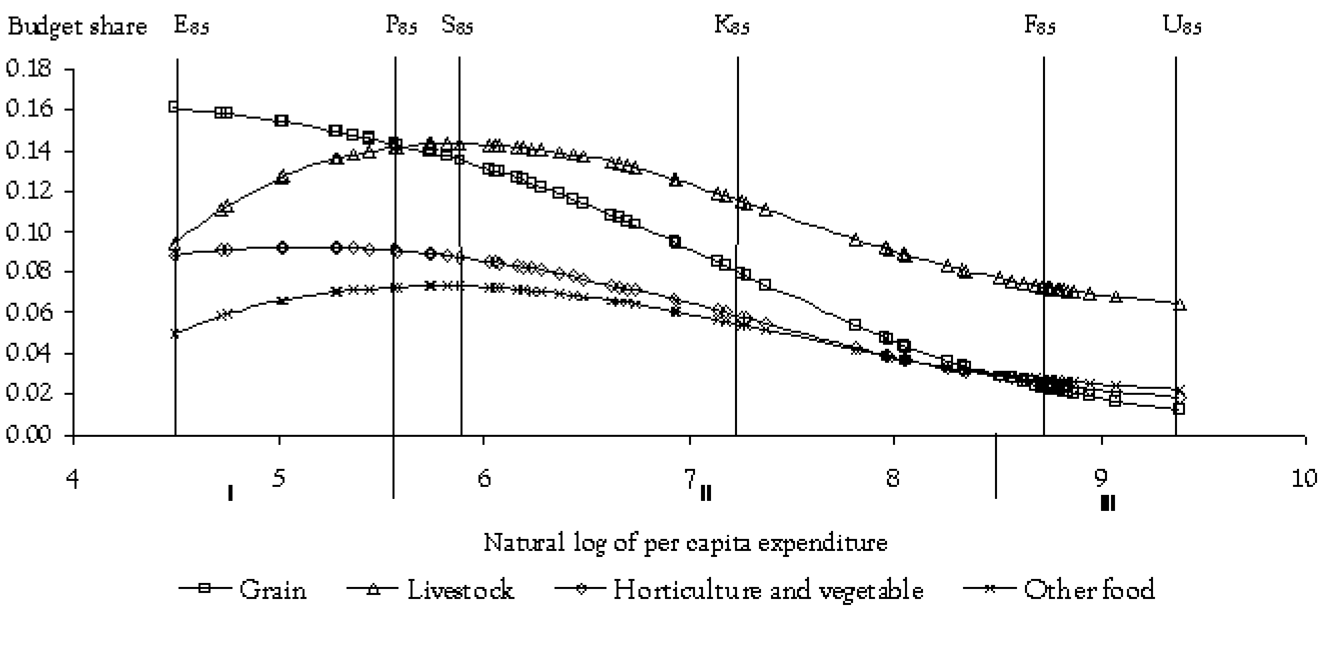
1 Introduction

In the 1990s there has been a marked shift in the composition of grains and livestock trade in favour of processed livestock products. The value of coarse grains trade peaked in 1981 at about US$ 20 billion. By contrast, global trade in cattle and other meat products amounted to US$ 10.8 and US$ 11.7 billion, respectively in 1981, but by 1995 their value had risen to US$ 22.6 and US$ 29.0 billion, respectively, substantially surpassing trade in coarse grains (McDougall et al. 1998). There are a number of factors driving this changing profile of world trade.

The first is on the demand side. As per capita income grows, people tend to prefer a more diverse diet, and expenditures on some food items such as meats, beverages and fruit tend to grow faster than for staple food such as cereals and legumes (Figure 1). Delgado et al. (1999) observed that the less than one-quarter of the world's population living in the developed countries presently consume an average of three times the meat and five times the milk per capita as people in developing countries. Yet it is in developing countries where massive annual increases in the aggregate consumption of animal products are occurring. From the beginning of the 1970s to the mid-1990s, consumption of meat and milk in developing countries increased by 175 million tonnes, more than twice the increase that occurred in the developed countries. For the year 1990, Delgado et al. (1999) calculated that the market value of the increase in meat and milk consumption totaled about US$ 155 billion, more than twice the market value of increases in cereal consumption under the green revolution.



Source: Cranfield et al. (1998).
Figure 1. *Fitted budget shares for food products (evaluated at mean prices).*

A second factor driving the changing composition of world trade derives from the supply side, particularly in East Asia, where competition for scarce labour and capital with rapidly growing manufacturing activity, as well as environmental constraints, have limited expansion of livestock production (Coyle et al. 1998).

Thirdly, innovations in international transportation of livestock products via refrigerated containers and refrigerated bulk vessels have also contributed to the growth.

Finally, in some cases, such as beef imports into Japan, policy reforms have stimulated additional trade. Coyle et al. (1998) ascertained that, of these four forces, the basic demand and supply-side forces were most important in fuelling the changing composition of world food trade over the 1980–95 period.

But can we expect this relatively rapid growth in livestock trade to continue? Recent work by Cranfield et al. (1998) and Delgado et al. (1999) suggests that demand side forces are indeed in place to fuel such growth. They argue that the population growth, urbanisation and income growth that fuelled the increase in meat and milk consumption are expected to continue over the next several decades.

These demand side forces could explain the rapid growth in livestock product trade in the 1980s and 1990s. But what about the supply side? Why not just import grains and raise the livestock locally? Clearly this depends on a whole host of factors, including local environmental constraints, transport costs and relative levels of productivity in livestock production. One would guess that eventually developing countries will catch up with, or at least approach, productivity levels in Japan, the United States and Europe. Wouldn't it then make sense to ship the lower cost grains and grow the more labour-intensive livestock products locally? Sector-specific productivity considerations were absent from the Coyle et al. (1998) historical analysis, and those authors cite this as one of the possible explanations for the large, unexplained residual in their predicted shift from bulk to high value food trade.

Rae and Hertel (2000) tested for convergence in livestock productivity among the Asia–Pacific economies. They found evidence of recent convergence in productivity levels for pig and poultry production, but generally not in ruminant production. At the country level, significant 'catch-up' to North American levels was demonstrated for China (poultry and pigs), Australia (pigs, beef and milk), Korea (pigs and beef) and South-East Asia (pigs). For non-ruminant production, the speed with which the technology gap had been closing was greatest for China. The authors then attempt to draw out implications for trade in livestock and grains. However, their projections are simple extrapolations of past catch-up trends. Clearly there is a limit to the amount of catching-up that can occur, and this needs to be taken into account when making projections. In this paper we seek to improve on the Rae and Hertel (2000) effort by decomposing productivity growth into two parts. The first is an underlying trend in the technical frontier, while the second represents an individual country's movement towards that frontier. This calls for a different approach to productivity measurement, which will be developed in the next section.

This paper places particular emphasis on East Asian countries, and especially in China. While considerable past research effort has been directed at quantifying China's possible future role in international grain trade (Fan and Agcaoili-Sombilla 1997), a similar question arises with respect to trade in livestock products. China is a net exporter of pig meat, but in 1991 switched from a net exporter to a net importer of poultry meat. By 1995, China's pig meat exports were 230 thousand tonnes and net imports of poultry meat had reached 235 thousand tonnes, making China the third largest poultry meat importer in the world. On a value basis, China had a positive trade balance for livestock products in aggregate in 1995. Delgado et al. (1999) projected net exports for 2020 of 300 thousand tonnes for each of pig and poultry meat. Wang et al. (1998) made projections to 2005 under the assumption of elimination of China's meat import tariffs. When the pork tariff is eliminated, 2005 net imports would be 491 thousand tonnes (compared with a baseline of 91 thousand net exports in 2005). For poultry, elimination of the tariff gives net imports in 2005 of 989 thousand tonnes (compared with 2005 baseline net imports of 709 thousand tonnes). Recent unpublished research at the Organization for Economic Cooperation and Development (OECD 1998) projected declining pig meat net exports and a rapid increase in China’s poultry meat imports in the year 2004. Thus there seems to be a general agreement that China will remain a net exporter of pig meat in the absence of tariff reductions, but that the volume of such exports will diminish. However, the above findings would not hold true when it comes to China’s future trade status with respect to poultry meat.

2 Background and review of literature

2.1 Scope for improvements in livestock technology

Modern science has developed, and continues to develop a large number of technologies for enhancing the productivity of livestock production, processing and marketing activities. The use of exotic breeds has enabled genetic improvement within herds and flocks to be speeded up, and genetic improvement has been enhanced even further with the aid of biotechnology. The latter involves the use of living organisms to produce improvements within animals, such as the various genetic engineering (DNA) techniques to manipulate genetic material and to transfer genes from one organism to another. In such ways, animal quality may be rapidly upgraded through improvements in genetic make-up and in the rate of reproduction. Biotechnology has also supported improvements in feed efficiency, milk production, and in the development of vaccines. Numerous compounds and improved feed efficiency, such as the use of anabolic steroids in cattle have been developed to promote faster growth. Also becoming well known is the elevation of natural levels of somatotropins (naturally-occurring protein hormones) in cattle, pigs, poultry and sheep. Growth rates, feed efficiency and milk yields may all be increased.

In the area of animal health, biotechnology offers promise for the improved diagnosis and treatment of animal disease. Livestock health research will also benefit from the increasing resources available to human health research. For example, genomics is a new science applicable to both humans and livestock that permits sequencing and mapping of the genome (a genetic map of a living organism). Genomics takes advantage of the work of the genomes of disease organisms and permits the development of new generations of vaccines, including those that use recombinant antigens to pathological agents (Fitzhugh 1998; Delgado et al. 1999). Farmers in the developing regions typically lack low-cost, easy-to-use diagnostics, vaccines, and control strategies for disease organisms and vectors. Among the parasitic diseases, trypanosomiasis (sleeping sickness) transmitted by tsetse flies, poses an enormous constraint to cattle production in most of the humid and sub-humid zones of Africa. Other important parasitic diseases groups include helminthiasis and tick-borne diseases. Although helminths are rarely fatal, they become a limiting factor in the intensification stage. Ticks transmit diseases such as theileriosis (East Coast Fever) in eastern and southern Africa. An effective vaccine for this disease may soon be available with a potentially large impact in ruminant productivity in those countries (Delgado et al. 1999).

To improve feed quantity and quality, research to reduce costs and improve efficiency will have to be highly targeted. The identification of suitable traits and their molecular markers derived from crop breeders who use the markers to develop dual purpose crops with improved grain and protein content for humans and non-ruminants and higher quality crops residues for ruminants help improve the quality of tropical feeds. Plant genomics and phytochemistry will tackle anti-nutritional factors, some of which can be poisonous to ruminants. Microbial techniques also exist that can help enrich ruminant ecosystems with microbes that can better detoxify anti-nutritional factors.

Artificial insemination (AI) is a well-known reproductive technology, but recent developments in embryo transfer raise the possibility that it might replace AI. A range of associated techniques has been developed. The transfer of embryos from donor to recipient animals allows the build-up of genetically superior animals using lower-grade and inexpensive recipients. Thus herd improvement can be achieved at faster rates than with natural mating or AI. But this form of reproduction will not become widespread in the developing countries within the next 20 years (Cunningham 1997). Other techniques include the splitting of embryos to produce multiple copies of genetically identical animals, embryo cloning, in vitro fertilisation and sex determination. Recent advances in cloning of embryos could potentially have a large impact on livestock production, particularly of dairy cattle in the developed world. But this is still an area where a number of complex ethical issues have yet to be resolved (Cunningham 1997).

Numerous mechanical technologies have been developed for application on farms, and within processing and marketing systems. Some examples include electronic monitoring of individual animal performance and the use of computers to control feed rations and the animals' environment. Advances in herd health management through adjusted weaning age, animal flow and housing design have cut expenses on medications while increasing growth rates and feed efficiency. Robotic techniques are increasingly used in processing operations, and other techniques allow product shelf life to be extended and product quality to be enhanced.

Such developments are likely to continue rapidly in the future. Simpson et al. (1994) referred to a 1992 report (US Congress, OTA 1992) that lists 42 potentially available animal technologies as of 1992, of which 22 were expected to be available by 1995 and all but 9 by the year 2000. Of course, the success with which these can be brought into commercial use in the country of origin (in many cases the USA) to recipient countries in Asia, and the rate and success with which they may be adopted, will be influenced by many factors. Empirical research by economists typically focuses on estimating, and possibly extrapolating, the overall rate of adoption as evidenced in aggregate productivity indexes. This is the approach adopted here.

2.2 Measuring aggregate productivity

The basic concept in productivity measurement is total factor productivity (TFP), the ratio of an index of aggregate output to an index of aggregate input. Changes in TFP can be decomposed into components measuring changes in technical efficiency, scale and the state of technology (Capalbo 1988). The literature on TFP measurement has historically been divided into two strands, namely: the growth accounting (index number) approach and the econometric approach (Capalbo 1988; Capalbo and Antle 1988; Capalbo et al. 1991).

The index number approach involves the use of detailed accounts of inputs and outputs, aggregating them into input and output indices, then in turn using these indices to calculate TFP indexes. The literature seems to prefer the Divisia index, because it is defined in continuous time and is exact for the case of homogenous translog functions (Capalbo and Antle 1988). There are many ways to get a discrete approximation to the Divisia index. The Tornqvist approximation is the most commonly used because of the popularity of second-order approximations to cost and production functions. More specifically, if the logarithm of the cost function is quadratic in the logarithm of prices and output, then the Tornqvist index is the 'true' index. The translog function does not require inputs to be perfect substitutes, but rather permits all marginal productivities to adjust proportionally to changing prices. Hence the prices from different periods being compared enter the Divisia index to represent different marginal productivities.

The econometric approach to productivity measurement is based on statistical estimation of the production technology. It allows the researcher to relax some of the assumptions implicit in the index number approach, including neutrality of technical change, industry equilibrium, and (generally) constant returns to scale. Most studies use a flexible functional form to represent the technology (production or cost function) and econometrically estimate this function, its derivatives, or both. Technical change is generally specified using time-trend variables (Capalbo 1988; Capalbo and Antle 1988). However, this comes at the cost of new assumptions. For sufficient degrees of freedom, and to mitigate multicollinearity problems, it is generally necessary to aggregate input data into a relatively small number of categories thereby implying input separability. Another strong assumption is that, with a few exceptions (Dorfman and Foster 1991; Rudstrom and Foster 1993; Kalirajan et al. 1996), technological change is represented as a function of time. Additional assumptions of competitive pricing and efficient input utilisation must be made when estimating cost or profit functions. Finally, assumptions about the statistical properties of the data must be made.

Index numbers have been extensively used in the analysis of agricultural production. The US Department of Agriculture uses this methodology and the Department's Economic Research Service routinely publishes total factor productivity measures from production accounts (Ball 1984; Ball 1985; Ball et al. 1997). Jorgenson and Nishimizu (1978) have extended this methodology to cover inter-country comparisons of TFP. This has led to a literature on multi-lateral, total factor productivity indexes including applications to agriculture by Capalbo et al. (1990) and Capalbo et al. (1991). Ehui and Spencer (1993) have used the Divisia approach to TFP to measure the sustainability and economic viability of alternative farming systems in Africa. Developments in international comparisons of TFP can be found in Ball (1997).

Recently, a different approach to the use of index numbers has been developed, based on the pioneering article of Caves et al. (1982). Caves et al. (1982) proposed a framework for input, output and productivity measurement that does not proceed from a continuous time representation. As stated in Färe et al. (1996):

> *They revolutionised the index number approach to productivity measurement by abandoning the idea that these indexes were at best a discrete (and therefore inaccurate) approximation to the continuous time derivatives used in econometric approaches. Instead, they showed that index numbers could be based directly on very general representations of technology, namely distance functions.*

Färe et al. (1996) named these indexes after Sten Malmquist who first applied this methodology, in the context of consumption behaviour, in 1953.

Färe et al. (1994) implemented the Caves et al. (1982) distance function approach to productivity measurement using non-parametric methods. The Färe et al. (1994) approach does not require a specific functional form (Caves et al. (1982) assumed a translog structure), it does not require prices, and it can be implemented in a multiple-output setting with many inputs (no separability assumptions are required). Further- more, since they adopt a frontier function approach based on linear programming, inefficiencies are permitted, thereby relaxing the requirement for long run industry equilibrium. The resulting measures of efficiency are unit-free, so there is no problem in extending the methodology to wider comparisons.

For our purposes, the most important part of the Färe et al. (1994) work is that it offers a convenient decomposition of productivity changes due to changes in efficiency (catching-up), and changes in the frontier, 'technical change'. This decomposition, in turn, enables us to formally estimate the frontier, compared with the earlier assumption of Rae and Hertel (2000) that North American productivity levels defined that frontier.

3 Productivity growth, 'catching up' and technical change

Following Färe et al. (1994), we present here a simple decomposition of productivity growth assuming a single input (animal stock) producing a single output (meat) represented respectively by x and y in Figure 2. The technology is represented in the Figure by the production frontier S_t for period t and by the frontier S_{t+1} for period t + 1. The frontier is the boundary of technology in each year and is defined as the maximum feasible output given input x. The Figure also shows two production points representing animal stock and production for a specific country in period t (x_t, y_t) and t + 1 (x_{t+1}, y_{t+1}).

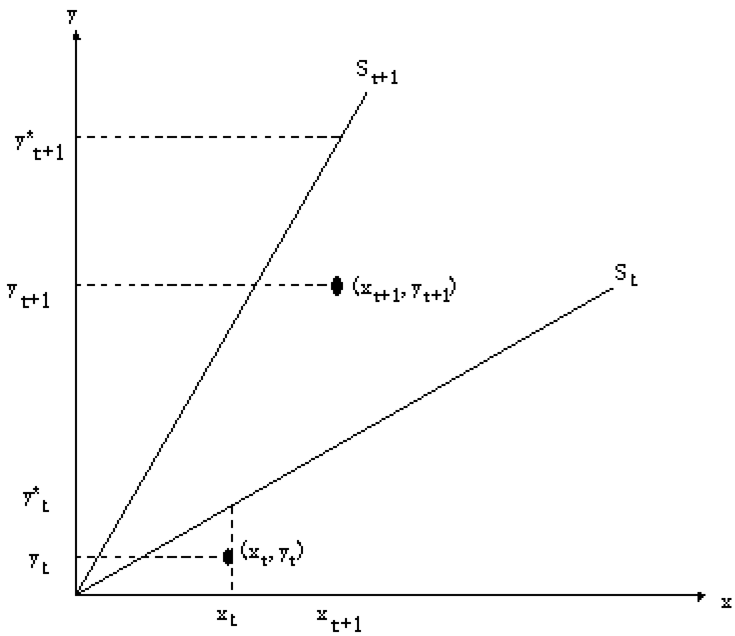


Figure 2. *Partial factor productivity growth and decomposition.*

A partial factor productivity (PFP) measure in period t and t + 1 for this country can be defined as:

$$PFP_t = \frac{y_t}{x_t} \text{ and } PFP_{t+1} = \frac{y_{t+1}}{x_{t+1}}$$

: (1)

Similarly, productivity on the frontier in period t and t + 1 for the same amounts of inputs used in this country is defined as:

$$F_t = \frac{y^*_t}{x_t} \text{ and } F_{t+1} = \frac{y^*_{t+1}}{x_{t+1}} \qquad (2)$$

Using productivity values as defined above, a simple index of productivity growth between period t and t +1 for our problem country is estimated as:

$$PGI_{t,t+1} = \frac{PFP_{t+1}}{PFP_t} \tag{3}$$

This index takes values greater than one if productivity between t and t + 1 is growing and values less than one if productivity is shrinking. Productivity growth as measured by this index can be decomposed in a catching-up (efficiency) and a technical change effect by simply multiplying the right hand side of equation (3) by $(F_{t+1}/F_t)*(F_t/F_{t+1}) = 1$ with F being productivity at the frontier as defined in equation (2). Rearranging terms we obtain:

$$PGI_{t,t+1} = \left[\frac{PFP_{t+1} \;/\; F_{t+1}}{PFP_t \;/\; F_t}\right] * \left[\frac{F_{t+1}}{F_t}\right] \tag{4}$$

The first term on the right hand side of equation (4) is an index measuring catching- up in terms of the rate at which the problem country is approaching or moving away from the frontier. This is the case because the ratios PFP_t/F_t and PFP_{t+1}/F_{t+1} measure how far the country is from the frontier in period t and t + 1, respectively. The second term of equation (4) is an index of technical change, measuring productivity growth in the frontier between t and t + 1. The catching-up index takes values greater than one if the country is catching-up to the frontier. Values greater than one for the technical change index imply that the sector is experiencing technical progress.

4 Productivity growth and decomposition for 1961–97

Our data on the global livestock sector are drawn from FAOSTAT 1998. In particular, data on livestock production and animal stocks covering the period 1961–97 for ten countries/regions were used to estimate the Malmquist index and the two components of productivity change identified above. Note that since we do not have a complete inventory of inputs used in livestock production, our measurement of ‘output per head of livestock’ is only a partial, not total, factor productivity indicator. (It is very difficult to obtain input allocations for the production of agricultural commodities, since most farms produce multiple products.) From this point on, we will refer to our measure of partial factor productivity simply as ‘productivity’. However, it should be borne in mind that this measure is fundamentally limited and will be inaccurate in the face of substantial factor substitution.

The Malmquist index and its components are estimated for each region and for the period 1961–97 using the distance functions as explained in the previous section. Table 1 reports the average annual rate of productivity growth over the sample period, for each country/sector pair in the sample, reported as a ratio of productivity in the year t + 1 and t.

Table 1. *Average annual productivity growth.*

	Pigs		Beef		Poultry		Milk	
Region	1991–97	1961–97	1991–97	1961–97	1991–97	1961–97	1991–97	1961–97
Australia	0.80	1.62	0.26	1.00	1.00	3.03	2.19	2.33
China	3.01	4.46	0.41	1.66	11.78	2.89	0.03	0.70
Japan	–0.08	1.59	–0.05	2.27	–0.43	2.20	1.59	1.56
Korea	0.22	2.53	8.09	1.87	2.81	3.05	0.91	3.73
New Zealand	1.01	1.86	–0.70	1.37	2.06	4.97	2.55	0.54
South-East Asia	0.73	1.98	–0.17	0.42	0.01	1.26	1.87	1.58
North America	0.92	0.99	0.59	1.03	2.99	2.36	1.95	2.39
EU	0.87	0.75	0.26	1.28	2.06	2.94	2.09	1.75
South America	2.49	1.19	0.70	0.14	1.91	3.20	1.41	0.46
Sub-Saharan Africa	0.66	0.20	0.03	–0.08	0.20	0.94	0.30	0.45
Geometric mean	1.06	1.71	0.91	1.09	2.39	2.68	1.49	1.54

We can see that poultry production was on average the most dynamic sector with ruminant production showing lower productivity growth. Most of the regions show smaller growth rates in the last 10 years. Exceptions are China in poultry production and South America in pigs, milk and poultry production. In the case of poultry production, China exhibits the highest rate of productivity growth over the last period (11.78% per year). Beef producers in sub-Saharan Africa actually experienced technological regress over the 1961–97 sample period.

However, examination of Table 1 raises more questions than it answers: Can we expect the high rate of productivity growth in China’s pig production to continue? How much of this rapid growth was due to catching-up, which is eventually doomed to diminish in significance? Table 2 presents the Färe et al. (1994) decomposition of productivity growth into country-specific catching-up growth rates (main body of the table) and worldwide frontier (technical change) growth rates (bottom row of the table). Given the importance of more recent developments in formulating projections into the future, we report separately the changes for the full sample period and the decade of the 1990s (1991–97). Based on Table 2, we can see that efficiency growth differs among sectors. Productivity growth in pig production since 1961 is largely due to catching-up in the developing regions, especially in the case of China and South America in the 1991–97 period. China's growth proceeded at an average annual rate of 3.7% explaining most of its productivity growth. Movement in the pig frontier was relatively low (0.7% per year) and appears to be slowing down (0.5% per year in the 1990s).

Table 2. *Average annual catching-up and technical change growth rates (in percentage).*

	Catching-up							
	Pigs		Beef		Poultry		Milk	
Region	1991–97	1961–97	1991–97	1961–97	1991–97	1961–97	1991–97	1961–97
Australia	–0.3	0.9	0.3	–0.7	–1.9	0.6	0.2	0.4
China	2.6	3.7	0.5	–0.1	8.6	0.5	–1.9	–1.2
Japan	–0.5	0.8	0	0.5	–3.3	–0.2	–0.4	–0.4
Korea	–0.2	1.8	8.1	0.1	–0.2	0.7	–1	1.7
New Zealand	0.5	1.1	–0.7	–0.4	–0.9	2.5	0.6	–1.4
South-East Asia	0.3	1.2	–0.1	–1.3	–2.9	–1.1	–0.1	–0.4
North America	0.5	0.2	0.6	–0.7	0	0	0	0.4
EU (15)	0.4	0	0.3	–0.4	–0.9	0.6	0.1	–0.2
South America	2	0.4	0.7	–1.6	–1	0.8	–0.5	–1.5
Sub-Saharan Africa	0.2	–0.5	0.1	–1.8	–2.7	–1.4	–1.6	–1.5
Mean	0.5	0.9	1.0	–0.6	–0.7	0.3	–0.5	–0.4
Technical change	0.5	0.7	0.0	1.7	3	2.4	2	2

Poultry and milk productivity offer a very different picture from developments in the pig sector. Here, it is movement in the frontier that has been dominating the industry over the past three decades. Indeed, despite reasonably rapid productivity growth, many of the regions have been falling further behind, as indicated by a value for catching-up index that is less than one. These are clearly the most dynamic sectors and the ones where there is the greatest future potential for growth due to catching-up. Of course, there are some notable exceptions. Poultry production in China has been catching-up at a remarkable pace (more than 8% per year) in the 1990s. Korean catch-up in beef production over the same period shows a similar growth (8.1% per year).

It is quite enlightening to also examine the time path of cumulative Malmquist indexes calculated as the sequential multiplicative products of the annual indexes. Figures 3a and 3b display these charts for pig and poultry production in China. In poultry production, it is clear from Figure 3b that technical change has been driving growth in productivity until the 1990s. Note, however, the sharp upturn in catching-up at the end of the sample. This is why we picked up the high growth rate for the 1990s in Table 2. Because China was falling behind the frontier during most of the sample period, the technical change (frontier) index is above the total Malmquist index until very recently. China's pig production, shown in Figure 3a, offers a striking contrast to the case of poultry. Here, there is very little growth in the frontier, with virtually all of the growth fuelled by catching up. This evidence suggests that modernisation of the pig sector in China may have commenced around a decade earlier than was the case for poultry.

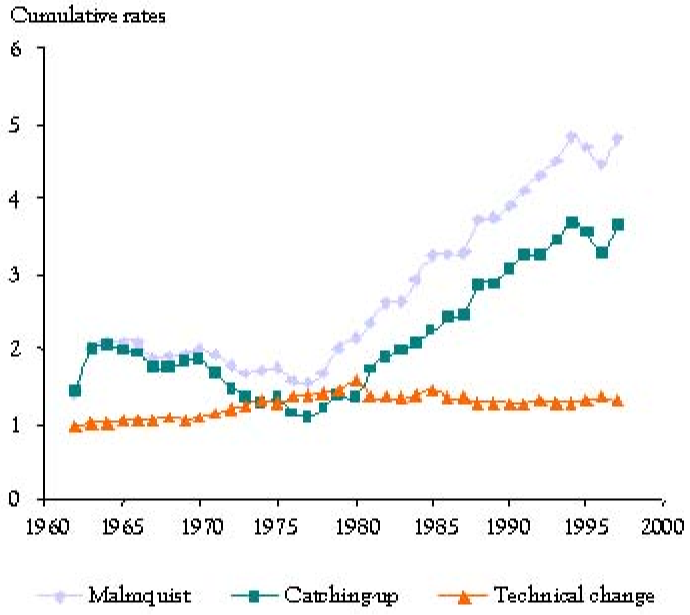


Figure 3a. *Cumulative productivity growth rates for China, pigs.*

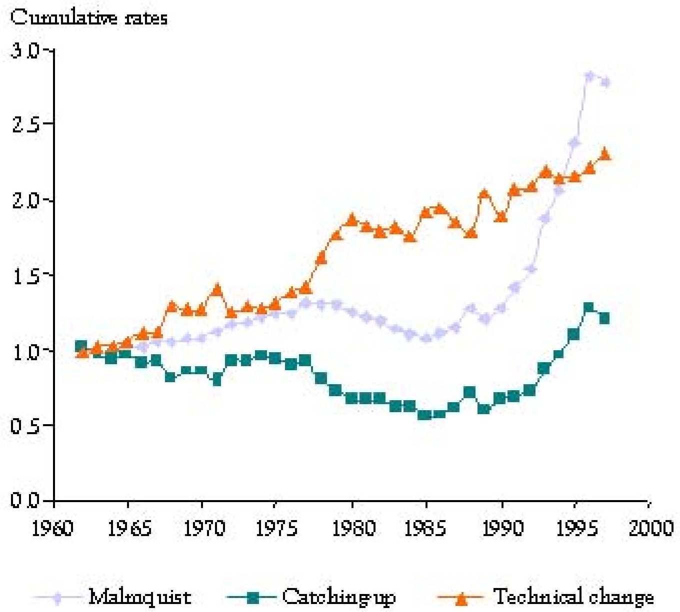


Figure 3b. *Cumulative productivity growth rates for China, poultry.*

5 Productivity forecasts

In this section we seek to develop projections of technological change in livestock productivity to the year 2005. We do so by making separate projections of the catching-up and technical change portions of productivity.

5.1 Catching-up and the logistic function

In the case of catching-up, we assume that the observable growth in productivity can be modelled as a diffusion process of new technologies. Previous studies (Griliches 1957 and Jarvis 1981) have shown that the cumulative adoption path often follows a logistic curve. Initially, productivity changes slowly because new innovations take some time to be adopted—usually there is the need of adapting the new technologies to different conditions to those of the country that generated the innovation. After this, a period of rapid growth is expected (e.g. as the risk of applying the new technology is reduced). This is illustrated by the case of China's pork production in the 1990s. Finally, productivity growth slows when nearly all producers who will find the technology profitable have adopted, and the process reaches a stable ceiling.

We specify the following logistic function to represent the catching up process for each of the regions in the sample:

$$Z_t = \frac{K}{1 + e^{-\alpha - \beta t}} \tag{5}$$

In this equation, the parameters and determine the shape of the logistic relationship for each region. The parameter K determines the ceiling, or maximum productivity level, to which the region in question is expected to converge. In estimating this relationship, we use actual observed values for K. These are equal to the maximum productivity value for each sector among all countries in each year.

The parameters of the logistic function are estimated by the following transformation:

$$Y_t = \log\left[\frac{Z_t}{K_t - Z_t}\right] = \alpha + \beta t \tag{6}$$

using an iterative Cochrane–Orcutt (C–O) procedure to correct for autocorrelation when necessary. First, a logistic functional form is assumed for all regions and the parameters estimated for periods of different length (all including the last year). The period for which the R^2 is higher is considered the period for which there is evidence of technology diffusion following the logistic pattern. For some of the regions, the logistic functional form clearly does not describe the diffusion process. According to the results, the regions can be classified in one of the following categories:

- Regions with a good fit of the logistic (high R^2, highly significant and positive $\hat{\beta}$ coefficients) were assumed to exhibit diffusion processes of new technology following this pattern.
- Regions with high productivity that resulted in poor fits of the logistic (low R^2 and non-significant coefficients) were considered ‘frontier regions’. The regions under this group are Japan, EU, North America and Korea in pig production; Australia, New Zealand, North America and EU in poultry production, and Japan in beef production. In pig and poultry production, all the ‘frontier’ regions differ by less than 20% from the region with the maximum productivity value. Productivity in these regions is assumed to grow at the frontier growth rate.
- Regions that resulted in poor fits of the logistic but cannot be considered as being at the frontier, where the exponential functional form is the one that best represents the diffusion process of new technology in general. This is the case of Japan, South-east Asia and sub-Saharan Africa in poultry production and Australia, New Zealand, South-east Asia and North America in beef production.
- None of the commonly used functional forms show a good fit for the diffusion process of beef production in sub-Saharan Africa, where there is little evidence of productivity growth in the past three decades (Table 1). For this particular case, the mean productivity value for the period is used as the forecast, using the errors with respect to the mean to generate a distribution for the forecast.

5.2 Technical change—Estimation of the frontier

While we are able to use actual observations of the frontier in estimating the logistic function, when it comes to forecasting, we need some way of predicting the evolution of this productivity ceiling. We choose to make this a simple function of time, as follows:

$$K_t = e^{\mu+\gamma\tau} \qquad (7)$$

Results from estimation of the different models are provided in Tables 3, 4 and 5. The bottom portions of these tables show the results of the estimation procedure of the productivity frontier for pigs, poultry and beef. The coefficients of the logistic and of the exponential reflect the diffusion speed of the technology. The high speed of diffusion of new technology in China, Australia and New Zealand in pig production; China and Korea in poultry production and Korea in beef production can be related with the efficiency gains and catching up of this regions. The relatively high coefficients for Australia, New Zealand, North America and EU in poultry production can be interpreted as the speed of diffusion of new technology in the frontier. The speed of the logistic diffusion process of technology in poultry production in South America is very low probably reflecting the fact that the production ceiling for this region is far below the fitted frontier.

Table 3. *Parameters and regression statistics in pig production.*

	Logistic diffusion process							Diffusion
		Adjusted 2	^	Standard	^	Standard	^	Standard	

Region	Procedure*	R	a	error	β	error	r	error	period
Australia	C–O	0.87	–1.57	0.40	0.11	0.02	0.46	0.17	1972–97
China	C–O	0.97	–2.98	0.19	0.09	0.01	0.57	0.17	1976–97
New Zealand	OLS	0.86	–1.63	0.24	0.10	0.01	–	–	1976–97
South-East Asia	C–O	0.93	–1.42	0.12	0.06	0.00	0.37	0.19	1973–97
South America	OLS	0.88	–1.69	0.12	0.03	0.00	–	–	1989–97
Sub-Saharan Africa	OLS	0.77	–1.78	0.07	0.02	0.00	–	–	1979–97
	Exponential frontier**								
	Procedure	Adjusted R^2	$\hat{\mu}$	Standard error	$\hat{g}$	Standard error	r	Standard error	
	C–O	0.89	4.69	8.65E–02	7.74E–03	3.53E–03	0.90	0.07	

* C–O = Cochrane–Orcutt; OLS = Ordinary least squares.
** Japan, EU, North America and Korea.

Table 4. *Parameters and regression statistics in poultry production.*

Region	Procedure*	Adjusted R^2	$\hat{a}$	Standard error	$\hat{\beta}$	Standard error	$\hat{r}$	Standard error	Diffusion period
	Logistic diffusion process								
China	OLS	0.95	–5.494	0.328	0.127	0.010	–	–	1989–97
Korea	C–O	0.78	–1.629	0.510	0.059	0.018	0.598	0.179	1978–97
South America	OLS	0.71	–0.208	0.043	0.018	0.002	–	–	1961–97
	Exponential diffusion process								
	Procedure	Adjusted R^2	$\hat{\mu}$	Standard error	$\hat{g}$	Standard error	r	Standard error	
Japan	C–O	0.97	0.617	0.194	0.023	0.007	0.953	0.050	1961–97
South-East Asia	C–O	0.91	0.329	0.184	0.012	0.007	0.954	0.049	1961–97
Sub-Saharan Africa	C–O	0.99	–0.073	0.045	0.010	0.002	0.951	0.051	1961–97
	Exponential frontier**								
	Procedure	Adjusted R^2	$\hat{\mu}$	Standard error	$\hat{g}$	Standard error	r	Standard error	
	C–O	0.96	1.21	3.94E–02	2.40E–02	1.77E–03	0.598	0.1317	

* C–O = Cochrane–Orcutt; OLS = Ordinary least squares.
** Australia, New Zealand, N. America and EU.

Table 5. *Parameters and regression statistics in beef production.*

Region	Procedure*	Adjusted R^2	$\hat{\mu}$	Standard error	$\hat{\beta}$	Standard error	$\hat{r}$	Standard error	Diffusion period
	Logistic diffusion process								
China	C–O	0.84	–1.511	0.213	0.028	0.007	0.624	0.179	1978–97
Korea	OLS	0.58	–2.927	0.968	0.113	0.031	–	–	1986–97
South America	OLS	0.92	–0.745	0.098	0.022	0.003	–	–	1991–97
EU	OLS	0.79	0.108	0.124	0.021	0.004	–	–	1989–97
	Exponential diffusion process								
	Procedure	Adjusted R^2	$\hat{\mu}$	Standard error	$\hat{g}$	Standard error	r	Standard error	Diffusion
Australia	C–O	0.93	5.004	0.030	0.010	0.001	0.707	0.116	1961–97
New Zealand	C–O	0.93	4.707	0.056	0.015	0.002	0.769	0.105	1961–97
South-East Asia	C–O	0.71	5.102	0.037	0.004	0.002	0.698	0.118	1961–97
North America	C–O	0.95	5.367	0.022	0.010	0.001	0.656	0.124	1961–97
	Exponential frontier**								
	Procedure	Adjusted R^2	$\hat{\mu}$	Standard error	$\hat{g}$	Standard error	r	Standard error	
	C–O	0.99	5.359	0.056	0.018	0.002	0.894	0.074	

* C–O = Cochrane–Orcutt; OLS = Ordinary least squares.
** Japan.

5.3 Forecasting

For purposes of forecasting, it is useful to have some idea of the possible distribution of outcomes, not just a single point-estimate. A distribution of the forecasts for each sector was approximated using the Efron bootstrapping method (Dorfman et al. 1990). The methodology proceeds in the following steps:

i. The residuals from the regression of Y_t on t (equation 6) are scaled by a factor of $(T/(T - k))^{1/2}$ and assigned mass 1/T.
ii. ε_t* is chosen by random draw with replacement from (i) and added to the right hand side of equation (6) to generate a new vector of quantities Y_t*.
iii. New parameter estimates (a^*, b^*, r^*) are generated from regressing Y_t* on t and then used to generate a forecast.
iv. Steps (ii) and (iii) are repeated many times by redrawing from (i) and used to create a distribution for the forecasts.
v. To consider the effect of the frontier's forecast in China's productivity forecast, steps (i) to (iv) are used to generate a distribution of the frontier's forecast. Values of K are chosen by random draw simultaneously with ε^*_t in step (ii) and used in (iii) to generate the forecast.

Tables 6, 7 and 8 summarise the mean, standard deviation and implied growth rates for productivity in these sectors. Table 9 decomposes these growth rates into the portion attributable to catching-up and further decomposes that attributable to movement in the frontier. Catching-up in productivity growth is relevant in pig production in China and South-

East Asia, in poultry production in China and in beef production in Korea. The change in the distance to the frontier as shown in Table 10 confirms this. In particular, productivity in China's poultry production is expected to grow twice as fast as for pigs (9.81% vs. 4.5% per year) over the forecasted period. Compare this with the forecasted developing world total production annual growth rate of 3.0% and 2.8% for poultry and pork, respectively for the period 1993–2020 (Delgado et al. 1999). Poultry production is higher on both counts by about three times—that is, the frontier in poultry productivity is projected to grow three times as fast as for pigs over this period—and China is expected to continue rapid catch-up in poultry productivity as well. In the case of pigs, slower growth in the frontier, coupled with current levels of productivity, which are closer to that frontier (66% in 2005), translate into slower overall productivity growth.

Table 6. *Productivity forecasts and growth in pig production.*

	Productivity forecast					Rates of growth (%)	
	Mean	Standard deviation	Maximum value	Minimum value	Productivity 1995	Total growth	Annual growth
Frontier*	160	1.80	166	154	137	16.8	1.42
Logistic forecast							
Australia	156	3.92	168	142	132	17.9	1.51
China	124	3.62	135	109	77	62.3	4.50
New Zealand	152	3.88	164	137	118	28.3	2.29
South-East Asia	119	3.43	129	108	85	40.3	3.12
South America	62	1.76	68	56	45	38.5	3.01
Sub-Saharan Africa	44	1.53	50	39	33	35.4	2.79
* US, EU, Japan and Korea.							

Table 7. *Productivity forecasts and growth in poultry production.*

	Productivity forecast					Rates of growth (%)	
	Mean	Standard deviation	Maximum value	Minimum value	Productivity 1995	Total growth	Annual growth
Frontier*	9.95	0.13	10.41	9.56	6.95	43.1	3.31
Logistic forecast							
China	5.50	0.19	6.22	4.90	1.97	179.9	9.81
Korea	7.71	0.27	8.59	6.51	4.38	76.1	5.28
South America	6.43	0.20	7.15	5.81	4.70	36.8	2.89
Exponential forecast							
Japan	5.70	0.42	6.64	3.89	4.04	41.0	3.18
South-East Asia	2.63	0.11	2.89	2.25	2.09	25.7	2.10
Sub-Saharan Africa	1.47	0.02	1.52	1.37	1.29	13.6	1.17
*Australia, New Zealand, US and EU.							

Table 8. *Productivity forecasts and growth in beef production.*

	Productivity forecast					Rates of growth (%)	

	Mean	Standard deviation	Maximum value	Minimum value	Productivity 1995	Total growth	Annual growth
Frontier*	514	9	540	479	399	28.8	2.33
Logistic forecast							
China	229	8	255	192	140	63.5	4.57
Korea	459	15	500	373	283	61.9	4.48
EU	380	8	402	353	277	37.1	2.91
South America	287	6	304	267	204	40.6	3.15
Exponential forecast							
Australia	236	3	247	224	218	8.0	0.70
New Zealand	224	5	241	206	172	29.6	2.39
South-East Asia	200	3	213	189	189	5.8	0.51
North America	340	4	351	328	309	9.9	0.86
Sub-Saharan Africa	131	0	132	129	131	–0.3	–0.03
* Japan.							

Table 9. *Productivity growth decomposition 1995–2005 (percentage).*

	Pigs		Poultry		Beef	
Region	Catching-up	Total	Catching-up	Total	Catching-up	Total
Australia	0.9	17.8	4.1	40.8	–16.0	8.2
China	38.7	62.0	106.9	179.8	26.9	63.4
Japan	6.1	23.9	4.3	41.1	0.0	28.8
Korea	10.6	29.2	30.2	76.0	25.8	62.0
New Zealand	10.0	28.5	4.9	41.8	0.8	29.9
South-East Asia	19.8	39.8	–7.1	25.6	–17.7	6.0
North America	4.1	21.5	0.0	35.2	–14.7	9.9
EU	0.0	16.8	16.1	56.9	6.4	37.1
South America	17.9	37.6	1.2	36.8	9.2	40.7
Sub-Saharan Africa	15.3	34.6	–15.7	14.0	–22.7	–0.3
Technical change	16.8		35.2		28.8	

Table 10. *Distance to the technological frontier.*

	Pigs		Poultry		Beef	
Region	1995	2005	1995	2005	1995	2005
Australia	0.97	0.98	0.96	1.00	0.55	0.46

China	0.56	0.78	0.27	0.55	0.35	0.45
Japan	0.94	1.00	0.55	0.57	1.00	1.00
Korea	0.90	1.00	0.60	0.77	0.71	0.89
New Zealand	0.86	0.95	0.95	1.00	0.43	0.44
South-East Asia	0.62	0.74	0.28	0.26	0.47	0.39
North America	0.96	1.00	1.00	1.00	0.77	0.66
EU	1.00	1.00	0.86	1.00	0.69	0.74
South America	0.33	0.39	0.64	0.65	0.51	0.56
Sub-Saharan Africa	0.24	0.28	0.18	0.15	0.33	0.25
Note: Most productive country = 1.						

6 Implications for trade: Projections to 2005

6.1 Trade model and database

Following the study of Rae and Hertel (2000) we incorporate the previous projections of productivity growth into a slightly modified version of the Global Trade Analysis Project (GTAP) applied general equilibrium model (Hertel 1997) to project national and regional production, consumption and trade flows between 1995 and 2005. This is a relatively standard, multiregion model built on a complete set of economic accounts and detailed inter-industry linkages for each of the economies represented. The GTAP production system distinguishes sectors by their intensities in five primary production factors: land (agricultural sectors only), natural resources (extractive sectors only), capital, and skilled and unskilled labour. In trade, products are differentiated by country of origin, allowing bilateral trade to be modelled, and bilateral international transport margins are incorporated and supplied by a global transport sector. The model is solved using GEMPACK (Harrison and Pearson 1996).

The 50 commodities in the version 4 GTAP database have been combined up to 14 commodity groups, of which 6 commodities (rice, wheat, other grains, oil crops, other crops and processed food) compete for use in the feedstuffs composite. (We modified the model to incorporate feedstuff substitution into the livestock production functions.) Livestock farming is represented by three aggregates: beef cattle (i.e. ruminant livestock), other livestock (i.e. non-ruminants) and raw milk production. These farming sectors provide inputs to the beef processing (ruminant meat), other meat (non-ruminant meat) and dairy products industries in each region. All remaining production sectors are aggregated into manufactures and services, or other natural resource based commodities. Regions are aggregated to match the regions reported in previous tables.

6.2 Macro-economic projections

The productivity catch-up, which we have projected here, is only part of the story of what will be happening in the world economy in the coming years. Other sectors will also be experiencing technological change. Income growth will tend to boost the demand for livestock products relative to grains, and in some regions there will be a strong shift away from food products altogether. On the supply side, the accumulation of skilled labour and capital in China can be expected to continue to promote the shift of activity away from agriculture, in favour of manufacturing and services.

As has become standard with the GTAP model, following the work of Gehlhar et al. (1994) projections are made through exogenous shocks to each region's endowments of physical capital, skilled and unskilled labour, population, and technology.[1] Table 11 reports the shocks to population, endowments and productivity that we assume in this paper. Forecasts for population, investment (capital stock), and labour force are based on the latest forecasts from the World Bank as of spring, 1999. Projected changes in skilled labour are based on expected increases in the stock of tertiary educated labour and are taken from Ahuja and Filmer (1995) for developing countries while projections for the Organization for Economic Cooperation and Development (OECD) countries are based on World Bank (1997) report. The stock of farmland in each region is simply held constant.

1. We also follow Gehlhar et al. (1994) suggestion that increasing the standard trade elasticities is appropriate in longer run simulations. For this eleven-year period, we double the standard GTAP values for the elasticities of substitution between imports and domestic goods and among imports from different sources.

Table 11. *Annual growth rates of exogenous variables used in the projections and gross domestic production growth.*

Region	Population	Endowments			Non-agricultural productivity	Forecast GDP*	World Bank forecast
		Unskilled labour	Skilled labour	Capital			
Australia	0.91	1.04	4.72	1.59	0.75	3.0	2.9
China	0.75	1.06	3.33	8.22	1.75	6.3	6.9
Japan	0.18	–0.26	2.57	0.33	0.25	0.8	0.9
Korea	0.74	0.64	4.74	1.53	1.75	2.9	3.4
New Zealand	0.73	0.71	4.72	2.28	0.25	2.3	2.3
South-East Asia	1.36	1.89	6.27	2.31	0.25	2.6	2.6
North America	0.78	0.89	3.02	3.04	0.75	2.7	2.5
EU	0.09	0.02	3.02	0.76	1.25	1.9	2.3
South America	1.37	1.94	5.50	0.96	1.25	2.7	3.0
Sub-Saharan Africa	2.55	2.84	5.97	1.05	0.75	3.0	3.3
ROW**	1.38	1.86	5.45	2.47	0.75	3.2	3.2

* GDP = gross domestic production
** ROW = rest of the world.

Forecasting productivity growth is notably difficult. Therefore, we adopt a rather simple approach which is transparent and which can be easily modified. First of all, based on the work of Bernard and Jones (1996), we observe that productivity growth tends to be more rapid in agriculture than in manufacturing, which in turn has a higher productivity growth rate than services. (They find virtually no evidence of productivity growth in mining where quality of reserves confounds the usually difficult measurement problems.) Based on their averages for the OECD as a whole (Bernard and Jones 1996, Table 1), we obtain the following multiples of the manufacturing productivity growth rate for the other sectors: (non-livestock) agriculture = 1.4 * manufactures, services = 0.5 * manufactures, and mining = 0 * manufactures. In this way, we are able to link productivity growth in each sector of the economy to a common metric—namely the rate of manufacture's productivity growth.

We then divide economies into four groups according to their overall rate of productivity growth: low, medium, high and very high. The assumed annual growth rates productivity in manufacturing value-added for these groups are as follows: 0.25, 0.75, 1.25 and 1.75% per year. As can be seen from Table 11, the low growth group includes Japan, South-East Asia, and New Zealand. The medium group includes the US, sub-Saharan Africa and the rest of the world. Higher productivity growth rates are foreseen for Australia, the EU and South America. Finally, Korea and China's productivity growth rates are expected to remain quite high—although somewhat lower than implied by the period prior to the Asian crisis. As a check on the plausibility of these assumptions, we compare our baseline cumulative gross domestic product (GDP) growth to that forecast by the World Bank (Table 11). Apart from China and Korea, all of these GDP projections are reasonably close. In order to hit the World Bank targets for these regions, we would have to raise the very high growth category still further. In light of the current macroeconomic uncertainty in that region, we opt for our more conservative projections.

Forecast distributions presented before are used to project livestock productivity in the different regions. Following Rae and Hertel (2000)[2] we apply these productivity shocks to both value-added and to the feed composite, to maintain a constant ratio of feed use per animal. Provided these shocks are positive, feed consumption per unit of output (the feed conversion ratio) will decrease. If this is the case, then the implications for feed demand, and hence for trade in grains and oilseeds as well as livestock products could be substantial. There is considerable evidence to support this assumption. A recent survey conducted by Wailes et al. (1998) gathered data on feed use across a range of enterprise and livestock types in seven provinces of China where the trend is towards development of specialised livestock production units and larger, more intensive management systems. They concluded that such structural changes would contribute to a declining demand for feed grains per kg of meat production. Another set of livestock and feeds projections for China are those of Simpson et al. (1994, Tables 7.6, 7.7 and 8.1), covering the period 1989–2000. Their projections imply little increase in feed inputs per animal so feed per unit output (the feed conversion ratio) shows negative growth, indicating increases in feed efficiency especially for poultry. This is consistent with the projections of Wang et al. (1998) who assume improvements in feed efficiency for all animal types and technologies. Finally, Tweeten (1998) reported projected annual USA growth rates in output per feed of 0.2% (beef and pigs), 0.6% (milk) and 2.0% (poultry). If USA is the source of much of the new livestock production technology that is transferred to China, then such improvements will eventually be felt in China.

2. Sub-Saharan Africa was omitted and the historical trends are used.

6.3 Results

We focus here on the impact of alternative livestock productivity scenarios on the changes of regional trade balances. Table 12 reports the change in sectoral trade balances for each region in our global simulation of the period 1995–2005. For convenience, Table 13 compares the trade balance of livestock products in 1995 with the projected trade balance of 2005. Even though productivity growth in livestock products is very high for China, there is little change in its trade balance between 1995 and 2005. This is because China's demand is also increasing sharply. All other Asian countries show negative impacts on the trade balance of livestock products. Among the developing regions, South America appears as a major exporter of beef and other meats with a five-fold increase in the trade for other meats and a two-and-a-half-fold increase in the trade for beef. On the other hand, sub-Saharan Africa shows deterioration in the trade balance for all livestock products. Developing regions all show negative trade balances in dairy products.

Table 12. *Change in trade balance (US$ × 10^6), 1995–2005.*

Products	Australia	China	Japan	Korea	New Zealand	South-East Asia	North America	EU	South America	Sub-Saharan Africa	ROW*
Rice	10	–1	1	0	0	–24	106	12	–8	–19	–93
Wheat	437	–2431	–83	–83	–11	–447	3651	2079	–72	–337	–3025
Other grains	30	–1651	–238	–178	–7	–393	2884	1023	17	–107	–1777
Oils	27	–553	–537	–181	–1	–531	2711	–525	933	59	–1625
Beef cattle	36	9	16	1	117	–178	–1406	2616	1312	–51	–2594
Other livestock	168	–40	–102	–365	328	–332	1620	2298	416	–76	–4098
Milk	0	0	0	0	0	0	0	0	0	0	0
Beef	180	148	–254	–244	260	–142	–13	899	1410	–262	–2354
Other meat	2	291	–483	–20	4	77	883	1871	722	–182	–3354
Dairy production	449	–195	–53	–37	–8	–299	113	1814	–216	–223	–1774
Other natural resources	3099	–49,283	7282	–8910	964	11,676	–5853	–6397	4085	7541	26,663
Processed food	977	–3791	–1234	918	111	–3823	4541	5413	3695	–733	–7789
Other crops	1361	–8554	–467	393	–6	–4343	2219	10,578	10,321	1042	–15,375
Manufactures	–7202	61,555	–7779	14,740	–2672	–12,956	–35,462	5200	–21,880	–10,634	–42,583
Services	424	4496	3931	–6035	922	11,717	24,006	–26,881	–735	3983	59,777

* ROW = rest of the world.

Table 13. *Trade balance in meat products (US$ × 106).*

Region	Beef		Other meat		Dairy	
	1995	2005	1995	2005	1995	2005
China	26	182	1619	1870	–24	–219
Japan	–4347	–4585	–6383	–6968	–845	–898
Korea	–761	–1004	–1441	–1826	–139	–176
South-East Asia	–519	–839	1641	1386	–1260	–1559
South America	1798	4520	301	1439	–1711	–1927
Sub-Saharan Africa	–10	–322	–196	–455	–496	–720
Australia	3086	3303	461	632	899	1349
New Zealand	1812	2189	537	869	1751	1743
North America	2241	822	5051	7554	186	299
EU	–1573	1942	716	4885	3029	4843
ROW*	–3279	–8228	–3676	–11,128	–3742	–5515

* ROW = rest of the world.

Table 14 compares trade balance of grains in 1995 and 2005. The most important result here is the projected increase in net grain imports to China. In general for the Asian countries we can see the trend toward increasing imports relative to exports in most of the agriculture-related sectors. This is particularly striking in the case of grains and other crops. It conforms to the findings of Delgado et al. (1999) who estimate that China will be a 46 million tonnes net importer of cereals by 2020.

Table 14. *Trade balance for grains (US$ × 10^6).*

Region	Rice		Wheat		Other grain		Oils	
	1995	2005	1995	2005	1995	2005	1995	2005
China	2	1	–1924	–4355	–989	–2640	377	–176
Japan	3	4	–1022	–1105	–3056	–3295	–2285	–2822
Korea	0	0	–459	–542	–1408	–1586	–504	–685
South-East Asia	27	3	–1387	–1834	–551	–944	–534	–1065
South America	–134	–142	–1212	–1285	–1195	–1179	839	1772
Sub-Saharan Africa	–43	–62	–752	–1090	–23	–130	125	184
Australia	7	17	1250	1687	53	82	31	59
New Zealand	0	0	–33	–44	–12	–20	–4	–5
North America	225	331	8260	11,912	8905	11789	6927	9638
EU	–182	–169	1076	3155	–294	729	–4973	–5497
ROW*	34	–59	–4538	–7563	–2827	–4604	–716	–2341

* ROW = rest of the world.

There are many uncertainties implicit in the productivity forecasts (Tables 6, 7 and 8) and in the macro-economic forecasts (Table 11). We now focus on the uncertainty associated with productivity growth in livestock production. This analysis revolves around the uncertainty associated with the change in sectoral trade balance. The average productivity shock, standard deviation, minimum and maximum shocks for non-ruminants and beef production are shown in Table 15. Mean and standard deviations are derived from the forecast distributions generated using the bootstrapping procedure.

The maximum and minimum values are calculated as the mean ± 4.5 times the standard deviation and a triangular distribution is assumed for the shocks. We use the Gaussian Quadrature approach to Systematic Sensitivity Analysis (SSA) proposed by de Vuyst and Preckel (1997) and automated by Arndt (1996) and Arndt and Pearson (1998) to draw a weighted sample from this distribution and generate standard deviations for our simulation results. Using the standard deviation associated with the simulated change in trade balances we can obtain Chebychev's 95% confidence intervals on the projected trade balance in 2005. These are reported in Tables 16, 17 and 18. The results for China suggest that it is not likely to be a net importer of livestock products in the year 2005. Results for other countries confirm that Asian countries will mostly be importers and the developed countries plus South America will be net exporters of livestock products.

Table 15. *Mean, standard deviation, maximum and minimum values for the productivity shocks as derived from the bootstrapped productivity forecasts.*

	Non-ruminants				Beef			
Region	Mean	SD*	Maximum	Minimum	Mean	SD*	Maximum	Minimum
Australia	1.311	0.016	1.382	1.239	1.080	0.014	1.143	1.017
China	1.781	0.042	1.972	1.590	1.635	0.033	1.783	1.487
Japan	1.119	0.009	1.160	1.078	1.289	0.018	1.369	1.208
Korea	1.419	0.018	1.499	1.338	1.619	0.032	1.764	1.474
New Zealand	1.368	0.017	1.442	1.294	1.296	0.023	1.400	1.193
South-East Asia	1.145	0.022	1.242	1.047	1.058	0.017	1.135	0.981
North America	1.294	0.011	1.344	1.244	1.099	0.011	1.150	1.048
EU	1.269	0.011	1.317	1.220	1.371	0.020	1.460	1.282
South America	1.371	0.031	1.510	1.231	1.406	0.019	1.493	1.320
Sub-Saharan Africa	1.159	0.018	1.240	1.078	0.997	0.004	1.013	0.980
* SD = standard deviation								

Table 16. *Chebychev's 95% confidence interval for the trade balance of Asian countries.*

	China			Japan			Korea			South-East Asia		
Products	Standard deviation	Interval		Standard deviation	Interval		Standard deviation	Interval		Standard deviation	Interval	
Rice	0	1	1	0	4	4	0	0	0	0	3	3
Wheat	6	–4327	–4384	0	–1105	–1105	0	–541	–542	0	–1832	–1836
Other grains	6	–2615	–2666	0	–3293	–3296	0	–1585	–1587	0	–943	–945
Total grain		–6941	–7049		–4394	–4397		–2126	–2129		–2772	–2778
Oils	5	–155	–198	0	–2820	–2824	0	–684	–686	0	–1064	–1067
Other crops	45	–8939	–9339	5	–9619	–9661	2	–1361	–1381	5	2375	2335
Total crops		–16,034	–16,586		–16,832	–16,882		–4171	–4196		–1460	–1510
Beef cattle	5	62	19	2	–147	–163	0	–6	–8	3	–391	–414
Beef	3	155	129	4	–4411	–4449	2	–986	–1007	1	–433	–441
Total ruminants		217	148		–4558	–4612		–992	–1015		–823	–855
Other livestock	250	1774	–478	9	–1101	–1186	7	–1584	–1648	16	–226	–374
Other meat	151	1907	547	7	–5795	–5854	3	–195	–225	23	1790	1581
Total non-ruminants		3680	69		–6896	–7039		–1779	–1873		1564	1207
Dairy products	1	–215	–222	0	–897	–899	0	–176	–176	0	–1557	–1561
Total livestock and products		3682	–5		–12,352	–12,550		–2947	–3065		–817	–1209
Processed food	24	–2571	–2783	4	–	–	2	473	456	5	3467	3423

					20,530	20,568						
Total food		–14,923	–19,374		–49,714	–49,999		–6646	–6805		1191	704
Other natural resources	125	–51,100	–52,228	3	–60,554	–60,583	0	–28,592	–28,592	13	26,768	26,647
Manufactures	211	108,077	106,182	13	209,182	209,064	11	30,244	30,141	27	–51,797	–52,044
Services	148	9566	8239	9	–31,732	–31,809	2	–1628	–1650	4	15,332	15,293
Total		51,620	42,818		67,183	66,672		–6621	–6906		–8507	–9400

Table 17. *Chebychev's 95% confidence interval for the trade balance of developed countries.*

Products	North America			EU			Australia			New Zealand		
	Standard deviation	Interval		Standard deviation	Interval		Standard deviation	Interval		Standard deviation	Interval	
Rice	0	332	331	0	–169	–170	0	17	17	0	0	0
Wheat	6	11,937	11,887	3	3168	3142	1	1690	1685	0	–44	–45
Other grains	5	11,813	11,766	3	741	718	0	83	82	0	–19	–20
Total grain		24,082	23,984		3739	3691		1789	1783		–63	–65
Oils	4	9657	9618	1	–5493	–5501	0	59	58	0	–5	–5
Other crops	11	–1903	–2005	17	–13,393	–13,545	2	3191	3171	1	350	339
Total crops		31,836	31,597		–15,148	–15,355		5040	5013		282	269
Beef cattle	61	–1489	–2042	45	2996	2588	6	441	388	4	206	171
Beef	19	2672	2503	46	–643	–1057	10	2934	2842	9	2044	1959
Total ruminants		1183	461		2353	1530		3375	3230		2249	2130
Other livestock	76	4085	3406	100	1843	943	16	654	510	12	802	693
Other meat	37	3974	3642	56	3740	3238	1	57	44	1	124	118
Total non-ruminants		8059	7048		5583	4181		711	554		926	811
Dairy products	1	302	297	3	4855	4830	0	1350	1347	2	1753	1732
Total livestock and products		9544	7806		12,791	10,541		5436	5131		4928	4673
Processed food	10	4403	4312	15	373	241	2	2620	2604	1	836	828
Total food		45,784	43,715		–1984	–4572		13,096	12,748		6046	5770
Other natural resources	20	–46,411	–46,587	18	–89,516	–89,682	7	16,480	16,414	3	2065	2037
Manufactures	101	–213,110	–214,020	135	71,790	70,579	11	–37,559	–37,657	7	–8050	–8117
Services	41	108,487	108,114	71	61,196	60,559	7	1652	1590	6	1883	1828
Total		–105,250	–108,778		41,485	36,884		–6331	–6906		1944	1519

Table 18. *Chebychev's 95% confidence interval for the trade balance of other countries.*

Products	South America			Sub-Saharan Africa			ROW*		
	Standard deviation	Interval		Standard deviation	Interval		Standard deviation	Interval	
Rice	0	–142	–143	0	–62	–62	0	–58	–60
Wheat	2	–1277	–1292	0	–1090	–1090	2	–7553	–7573
Other grains	1	–1173	–1184	0	–128	–132	1	–4597	–4610

Total grain		–2592	–2619		–1279	–1283		–12,208	–12,243
Oils	4	1790	1754	0	186	182	2	–2334	–2349
Other crops	33	27,736	27,440	11	10,076	9980	11	–20,964	–21,065
Total crops		26,933	26,575		8983	8879		–35,507	–35,656
Beef cattle	66	2112	1515	2	64	51	29	–3122	–3385
Beef	66	3004	2410	2	–369	–390	6	–4948	–5000
Total ruminants		5116	3925		–305	–339		–8071	–8385
Other livestock	63	683	118	7	118	54	64	–4914	–5489
Other meat	63	1322	756	3	–528	–554	40	–5748	–6109
Total non-ruminants		2005	874		–410	–500		–10,662	–11,598
Dairy products	0	–1926	–1928	0	–720	–720	1	–5510	–5520
Total livestock and products		5194	2871		–1434	–1559		–24,243	–25,503
Processed food	14	16,139	16,017	1	–560	–570	8	–14,085	–14,155
Total food		48,267	45,463		6990	6750		–73,835	–75,315
Other natural resources	15	27,815	27,677	6	33,959	33,906	35	132,832	132,521
Manufactures	166	–83,454	–84,952	10	–44,475	–44,563	23	–210,806	–211,014
Services	57	4670	4161	7	3212	3149	40	132,988	132,625
Total		–2702	–7650		–314	–759		–18,822	–21,183

* ROW = rest of the world.

7 Summary and conclusions

The particular goal of this research is to decompose the historical—and projected— changes in livestock productivity into two components: shifts in the global technology frontier, and movement towards that frontier by individual regions.

Our historical analysis shows that the situation can be very different across products for the same country. Mainly efficiency growth or catching-up can explain productivity growth in pig production in the developing regions since 1961. China's growth in efficiency explains most of its productivity growth in pig production. Movement in the pig frontier was relatively low and appears to be slowing down. Poultry and milk productivity offer a very different picture from developments in the pig sector. Here, it is movement in the frontier that has been dominating the industry over the past three decades and many of the regions have been falling further behind. These are clearly the most dynamic sectors and the ones where there is the greatest future potential for growth due to catching-up. However there are several important exceptions to this general trend. Poultry production in China and beef production in Korea have been catching-up to the frontier at a remarkable pace in the 1990s.

To assess the likely consequences of future changes in livestock productivity on international trade in livestock and related products, we used a modified version of the GTAP model of global trade to make projections to the year 2005. Uncertainty in future productivity growth rates was also taken into account. Our findings are that Asian countries show negative impacts on the trade balance of livestock products with the exception of China that will need high productivity growth rates between 1995 and 2005 to avoid deterioration of the trade balance in livestock products. In general, for the Asian countries we can see the trend toward increasing imports relative to exports in most of the agriculture-related sectors especially in the case of grains and other crops. Among the developing regions, South America appears as a major exporter of beef and other meats and sub-Saharan Africa shows deterioration in the trade balance of all livestock products. All developing regions will keep negative trade balances in dairy products.

By recognising the uncertainty associated with the estimates of livestock productivity growth worldwide, we obtained confidence intervals for the trade balances which show that China will still be a net exporter of livestock products in the year 2005 (in the absence of any major policy changes). Our results suggest that other East Asian countries will mostly be net importers and the developed countries and South America will be net exporters of livestock products.

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